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High-Brightness from an Unstable Resonator Mid-IR Semiconductor Laser (Postprint)

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14. ABSTRACT

We describe high-brightness, broad-area mid-IR semiconductor lasers. The optically pumped devices achieved higher brightness operation as unstable resonators. Each unstable resonator was realized by polishing or etching a diverging cylindrical mirror at one of the facets. For several mid-IR unstable resonator devices experimental near- and far-fields near threshold are shown, as well as at many times threshold. For an unstable resonator semiconductor laser operating at ~ 4.6 μm and at a high peak power of 6.7 W the device was observed to be nearly diffraction limited 25 times threshold. In comparison, a standard Fabry-Perot laser was observed to be 6 to 8 times diffraction limited when operated under similar conditions.

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High-Brightness from an Unstable Resonator Mid-IR Semiconductor Laser

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In this paper we review recent developments in high-power, optically pumped, mid-infrared semiconductor lasers. We have demonstrated that these lasers can produce high peak powers in the 5 to 15 W range, CW powers in excess of 2 W and lasing wavelengths in the 2 to 10 micron region.[1,2] However, these broad area lasers typically display degraded beam quality as the pump intensity is increased; they may go from 2-3 times diffraction limited near threshold to 8-15 times diffraction-limited at ~ 30 times threshold. This limits the devices applicability since it becomes difficult to couple the radiation into a small numerical aperture fiber or to focus the radiation in the far field. There are a large number of applications that would directly benefit from high power mid-IR output in a nearly diffraction limited beam. These applications include infrared countermeasures, free-space optical communication, remote sensing, laser marking, and various medical applications.

A number of approaches have been utilized in near-IR semiconductor diode lasers (electrically pumped lasers) to achieve high-power operation with diffraction limited output. These include tapered amplifiers[3], angled injection into traveling wave or reflective wave amplifiers[4], coupled narrow stripe lasers, and various unstable resonator (UR) geometries[5,6]. The UR laser concept is best understood by comparing it to the conventional Fabry-Perot (FP) laser. The conventional semiconductor laser uses an FP cavity defined by two parallel mirrors. The lasing mode undergoes multiple reflections at the cavity mirrors and the mode is directly counter-propagated. In contrast, the UR laser is characterized by counter- propagating diverging cylindrical waves diverging from fixed virtual source points. By avoiding direct counter-propagation UR's suppress filamentation and maintain excellent beam quality with all the radiation diverging from fixed high-brightness virtual source points. Consequently, the UR laser is a high brightness source since near diffraction-limited beam quality can be preserved even with broad laser cavities and under conditions of high current injection or optical pumping.

The optically pumped devices achieved higher brightness operation as unstable resonators. Each UR was realized by polishing a diverging cylindrical mirror at one of the facets. We form the mirror by a mechanical polishing procedure in which the chip is sandwiched between two metal blocks. On one side of the blocks cylindrical templates have previously been milled, conforming to the correct cylindrical figure. When the antimonide based chip is sandwiched between them, properly aligned, and mechanically polished a high-quality cylinder is formed with the desired radius of curvature and minimal facet damage. A typical top-down image and a facet image of a mechanically polished UR are shown in Fig. (1). The polishing process is highly robust such that no major facet damage is visible and only a small drop ($\approx$ 15 %) in the slope efficiency is observed in the operation of the unstable resonator as compared to the Fabry-Perot as can be seen in figure (2). A majority of this drop in power is due to the extra loss of the cavity due to geometric magnification of the radiation in the unstable resonator cavity. This resonator magnification, M, is conveniently quantified as:

$$M = \frac{V+L}{V-L} = \frac{\sqrt{L^2+RL}+L}{\sqrt{L^2+RL}-L}$$

where L is the cavity length and R is the cylindrical mirrors radius of curvature. Typical magnifications for the optically pumped UR's are from 2 to 4.

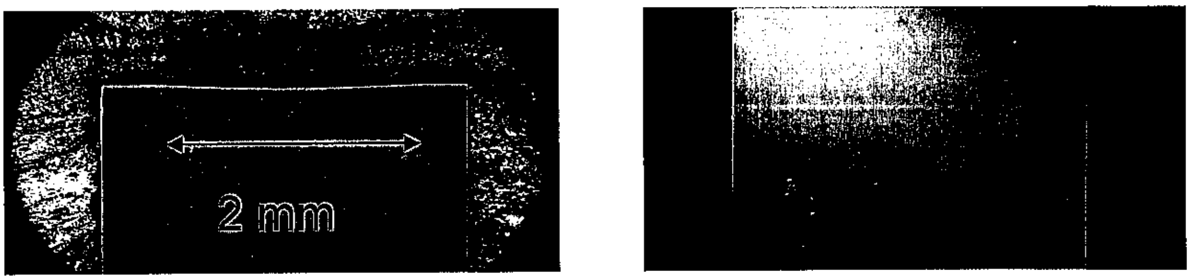

Figure (1). **Left**: Top-down view of the UR laser, the mirror sag is approximately 50 um. **Right**: Front facet image of the UR; the epilayers, not discernable, are on theleft side.

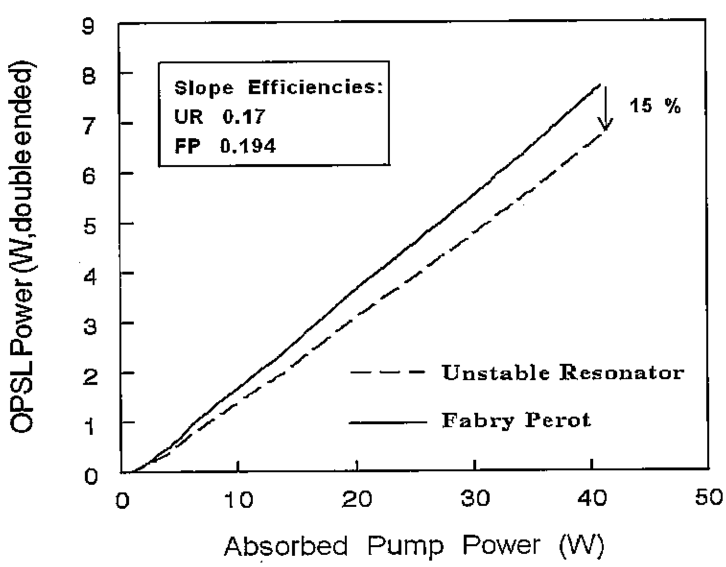

Figure (2) Comparison of the output power from an optically pumped unstable resonator vs. a Fabry-Perot laser.

Regenerative reimaging of the circulating radiation is the critical mechanism leading to high brightness from the virtual source point. These virtual source points, shown as V_+ and V_- in Fig. (3), are located at a distance $V = \pm \sqrt{(L^2 + LR)}$ from the flat facet. The left virtual source, V_+, is at an object distance (V+L) from the diverging mirror with focal length (-R/2). Upon reflection from the curved facet, the radiation forms a virtual image, V_-, at a distance (V-L) to the right of the curved facet.

In actual operation, we outcouple the radiation from the flat facet side of the device, so that the virtual waist of the lateral mode is located behind the output facet at a refractively reduced distance, D = V/n, in which the index of refraction is given by n~3.8. For a typical device geometry with L = 3500 μm and R = 10000 μm, this reduced distance is inside the device at approximately 1810 μm from the flat facet. In addition to the high brightness generated by the regenerative reimaging of the virtual source points, the natural divergence of the propagating mode tends to mitigate self-focusing filamentation, leading to further brightness improvements.[7,8]

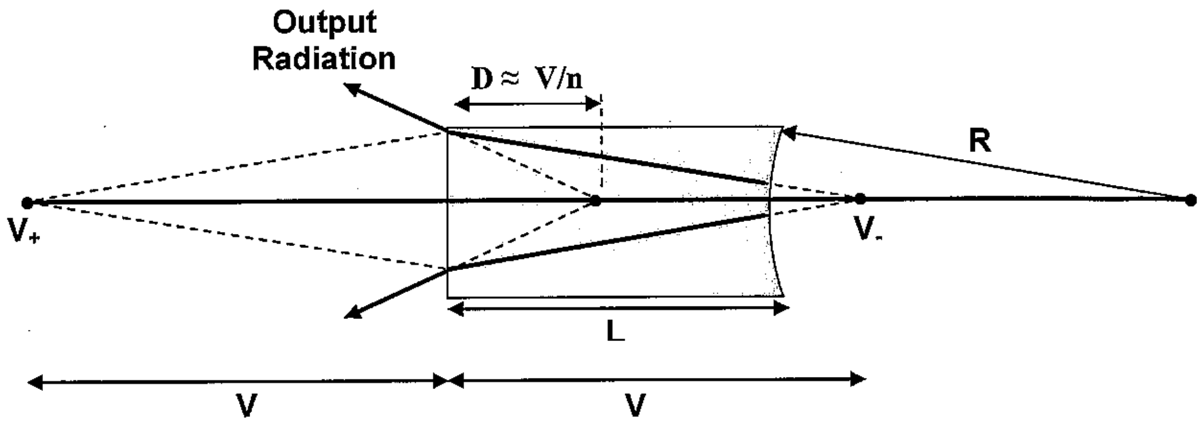

Figure (3). Schematic of unstable resonator showing virtual source points

For several mid-IR unstable resonator devices, we will show experimental near- and far-fields near threshold, as well as at many times threshold. For these devices, the far-field is realized by reimaging the high-brightness virtual source point located a distance D from the flat facet. This is shown in Fig.(4) for an unstable resonator semiconductor laser operating at ~ 4.6 μm and at a high peak power of 6.7 W. This device was observed to be nearly diffraction limited at 5 and 25 times threshold. In comparison, a standard Fabry-Perot laser was observed to be 6 to 8 times diffraction limited when operated under similar conditions.

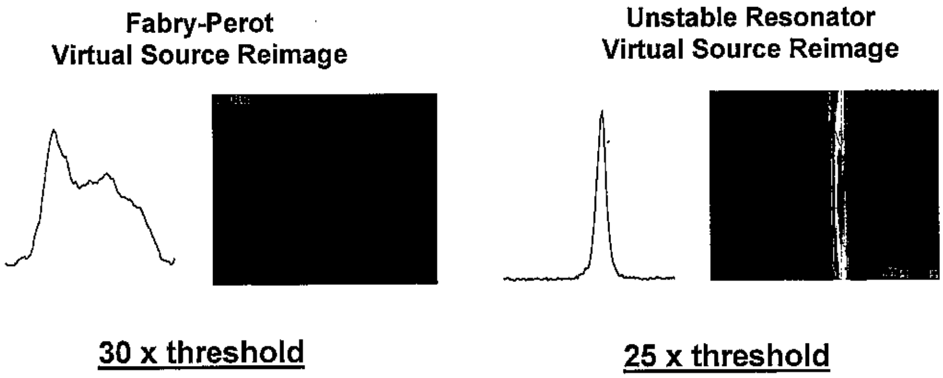

Figure (4). Fabry-Perot and unstable resonator showing the reimaged virtual point sources. The intensity maps are the reimages of the virtual sources at 30 and 25 times threshold, respectively. The reimaged spot sizes indicate the devices are operating 6-8 times and near the diffraction limit, respectively.

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